Using satellite-based remotely-sensed data to determine tropical cyclone size and structure characteristics

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LONG-TERM GOALS:

To exploit remote-sensing observations for tropical cyclone genesis, intensity, and structure information and use this information to develop objective, accurate multivariate analyses of tropical cyclone wind structure and intensity in oceanic regions where *in situ* observations are sparse.

OBJECTIVES:

The primary objective is to continue to use innovative signal-processing methodologies to extract tropical cyclone (TC) structure information, including genesis likelihood from clouds clusters, intensity information, and wind field structure information from remote-sensing platforms in oceanic regions where in situ observations are sparse. This information is used to develop objective, accurate analyses of tropical cyclone wind structure and intensity. Specific investigations include:

1. Developing a multivariate genesis parameter to create probabilistic forecasts of TCs within 24, 48, and 72 hours using the DAV signal in conjunction with other remote-sensing data including lightning flash rate data;
2. Developing methods using satellite observations to infer wind structure information;
3. Exploring improvements in TC model initialization using improved wind structure information; and
4. Exploring multi-variate, multi-temporal remote sensing data sets to provide structure and intensity information of TCs at different stages in their life cycles.

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By leveraging our past work on objective peak intensity estimation and genesis potential of cloud clusters using geostationary satellite imagery, we will explore whether more detailed wind structure can be extracted from remote sensing data. We will begin with the geostationary visible and infrared observations that are the basis of our earlier results, but we will also explore the blending of spatially and temporally-limited data sets such as those available at microwave frequencies on polar orbiting platforms, as well as land-based remote-sensing information including the Vaisala Long-Range Lightning Detection network. We will also continue to improve the current techniques we have developed for genesis and intensity estimation/prediction working with our partners at JTWC to improve the utility and functionality of those techniques.

APPROACH:

This work has multiple aspects to it and so the approach is somewhat non-uniform in reaching each goal we have set. Most of the work includes analyzing remote sensing data for signals that prove to have high correlation with the TC parameter we are interested in, whether genesis, intensity trends, or size parameter trends. Because of our previous work in the DAV parameter (from IR imagery, Piñeros et al. 2008; 2010; 2011), our starting point is to analyze that signal for further information on TC size and structure. We then use validating observations to check and train our technique. For wind structure we are limiting the training set to within 6 hours of USAF reconnaissance data availability for the Atlantic. For validation and detailed analysis of the physical processes that link the signals we extract from remote sensing observations and the physical structures/processes they represent, we use statistical analysis, model simulation studies, or subjective evaluation then establishes the validity/utility of our technique.

WORK COMPLETED:

1. A DAV-based objective, automated system to track the location and evolution of TCs in satellite imagery has been developed. The goal is to perform an objective, automated analysis of the TCs evolution, using the symmetry information provided by the DAV method. This will allow us to track the TC at early stages of development in order to improve the reliability of our genesis analysis and reduce the false positive rate. The system has been tested for a 2-week period of the 2009 western North Pacific season (Rodríguez-Herrera et al. 2013) and testing of the system for a longer period 2009-2012 is underway.

2. The deviation angle variance technique (DAV-T) was applied to the eastern North Pacific basin for both genesis prediction and intensity forecasting. As neither GOES-East nor GOES-West provide full coverage of the eastern North Pacific, an algorithm was developed to stich rectified satellite imagery together prior to applying the DAV-T. The parametric curve and two-dimensional parametric surface intensity algorithms were applied for the years 2005-2011 with overall root mean square (RMS) intensity errors of 13.4 kt and 12.7 kt respectively. A paper has been submitted to *Wea. Forecasting* reporting these results (Ritchie et al. 2013). In addition, the objective cloud cluster tracking algorithm (Rodríguez-Herrera et al. 2013) was also applied in the eastern North Pacific basin to follow cloud clusters that meet a set of thresholds including minimum lifetime, average brightness temperature, and a given DAV value to develop a genesis predictor.

3. Lightning flashes are being combined with the DAV-T signal for genesis to determine whether the DAV-T genesis prediction can be improved by incorporating other remote-sensing data that has shown

genesis distinguishing properties. Previous work in the group has shown that Lightning flash rates are a discriminator of genesis (Leary and Ritchie 2009). Current work completed includes: transforming individual lightning flash counts to a grid at half-hourly intervals for the period May to October; and statistically analyzing the gridded flash counts with respect to DAV values and cloud top temperature in order to evaluate the potential for a combined genesis predictor product.

4. A methodology to objectively obtain the symmetric and asymmetric wind field structure of TCs from satellite imagery has been developed. From this, a multiple linear regression model has been developed using the axisymmetric DAV signal, variables from the best track data, and environmental parameters from the Statistical Hurricane Intensity Prediction Scheme (SHIPS) model in order to determine the radial extent of the axisymmetric 34-, 50-, and 64-kt winds. Furthermore, the analysis has been repeated for each individual quadrant (NE, SE, SW, and NW) in order to extract asymmetric components of the wind field. Recombination of the symmetric and asymmetric components has produced a good representation of the wind field for various test cases of TCs compared with either basic SHIPS R34, R50, R64 values or subjectively with the H*Wind product. A manuscript is in preparation for *J. Atmos. Sci.* reporting these results (Dolling et al. 2013).

RESULTS:

a) Objective cloud cluster tracking algorithm

An objective, automatic tracking system has been developed to improve the DAV-based genesis prediction technique. It uses a number of user-defined thresholds to connect time- and/or space-separated detections of a single TC in infrared imagery. Although the thresholds are user defined, their choice is given in terms of typical physical parameters of TCs, such as a typical radius, cloud temperature, etc. The details of the tracking system are reported in Rodríguez-Herrera et al. (2013).

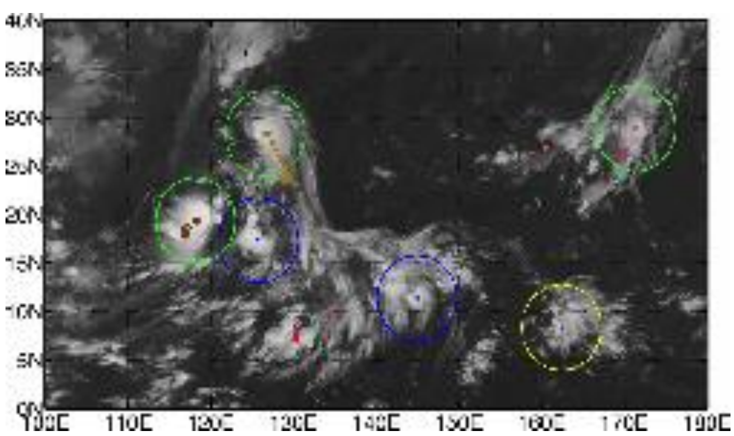

Figure 1: IR image of the western North Pacific overlaid with the results obtained with the objective, automatic tracking system.

Figure 1 shoes an IR image of the western North Pacific basin with a number of potentially developing cloud clusters being tracked by the objective, automated tracking system. The figure shows three types of current detections and the previous location of seven identified TCs with a latency time of 24 hours. The current detections, marked by a color circumference, are divided in blue new true detections (i.e., detections that satisfy all the thresholds in the tracking system and have not been previously identified), green true detections (i.e., detections that satisfy all the thresholds and are associated to a previously identified TC), and yellow track detections (i.e., detections that do not satisfy all the thresholds but have been associated to a previous true detection).

Table I shows the results of a tracking experiment carried out for the 2010 season over the western North Pacific between 0032 UTC 25 August and 2332 UTC 5 September. As shown in the table, the results of the objective, automatic tracking system were in good agreement with results obtained by

Storm Name	Start Date – Time (UTC)		Finish Date – Time (UTC)	
	Exp. Op.	Auto. Tracking	Exp. Op.	Auto. Tracking
Namtheun	08/25 – 2132	08/25 – 2132	08/30 – 2032	08/30 – 2032
Lionrock	08/28 – 0832	08/28 – 0232	09/01 – 2032	09/02 – 1232
Kompasu	08/28 – 1232	08/28 – 1232	09/01 – 1832	09/01 – 2332
Malou	09/03 – 2232	09/03 – 2232	09/05 – 2332	09/05 – 2332

Table 1. Summary of the objective, automatic tracking results obtained for the 2009 season in the western North Pacific between 0032 UTC 25 August and 2332 UTC 5 September.

expert operators following the evolution of the identified TCs. The table only includes the start/finish date and time to simplify the presentation of the results. The storm names reported in Table I are the names reported for those TCs in the best track archive of the Joint Typhoon Warning Center. We are continuing to verify the tracking tool using data from 2009-2012. Ultimately the statistics provided by the tracking tool will be used to develop a probabilistic genesis prediction tool.

b) DAV-T genesis prediction and estimation in the eastern North Pacific

The DAV-T has been successfully applied to the eastern North Pacific basin over the period 2005-2011, producing a best overall root mean square (RMS) error of 13.4 kt calculated using a radius of calculation of 200 km. Due to the variation in TC size found in the western North Pacific, the two-dimensional surface was also applied to this basin, which uses the DAV value computed from two different radii to then estimate the intensity of the TC. There was a slight RMS error improvement of 0.7 kt resulting from this methodology. The DAV-T estimated intensity (kt) compared to the National Hurricane Center best track estimates (red) for 2008 using 2005-2007 and 2009-2011 as the training set is shown in Fig. 2. The 2008 RMS intensity error is 10.0 kt (Ritchie et al. 2013).

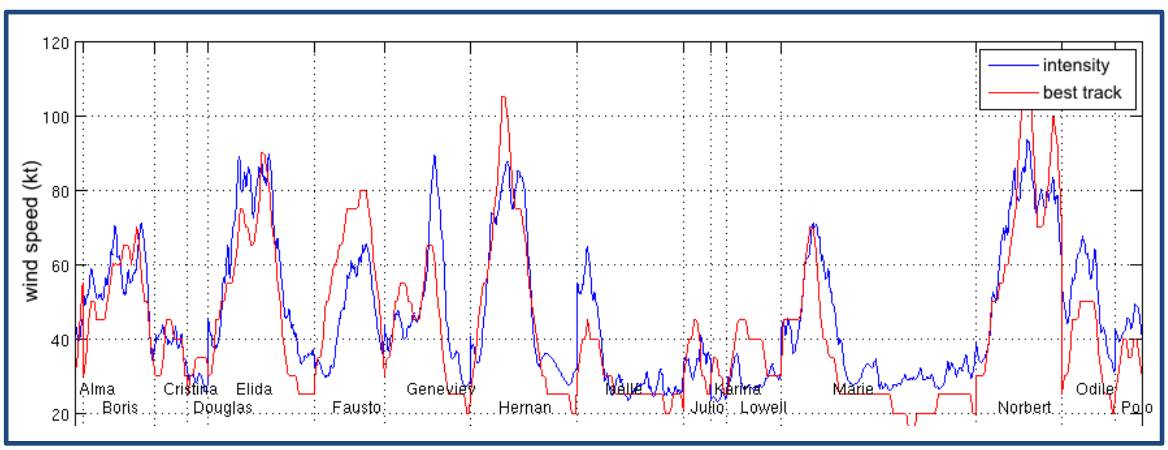

Figure 2: DAV intensity (kt; blue) and best track intensity (kt; red) for all storms in 2008. The DAV intensity estimates shown are made using 2005-2007 and 2009-2011 as the training set. 2008 had a best radius of 200 km and an associated RMS error of 10.0 kt.

Continuing work involves reducing the error made for high intensity estimates, as the performance of the DAV-T worsens as TCs become more intense. As the sigmoid may not be the best parametric curve for high intensity estimation, other methods are being investigated.

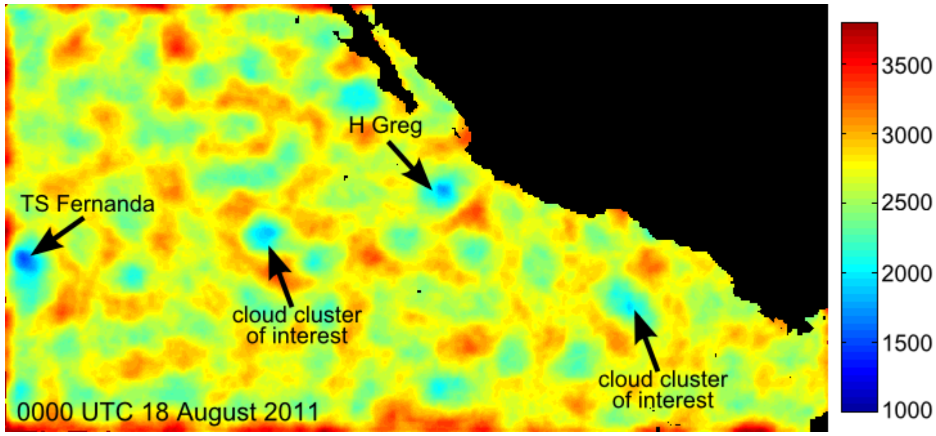

Figure 3: Map of DAV values (deg^2) at every pixel for 0000 UTC 18 August 2011. The two TCs depicted are Tropical Storm Fernanda (50 kt) and Hurricane Greg (65 kt). Note that Fernanda was a highly axisymmetric TC at this time.

For genesis prediction in the eastern North Pacific, maps of the DAV parameter are created (Fig. 3) by calculating the DAV parameter with regions of lower DAV values that coincide with clouds signifying cloud clusters that are organizing into tropical cyclones. An objective tracking technique (Rodríguez-Herrera et al. 2013) is being applied to the eastern North Pacific to follow cloud clusters that meet a set of thresholds including minimum lifetime, average brightness temperature, and a given DAV value. Different rates of true positives versus false positives are calculated based on these thresholds, and the results are currently being analyzed in order to determine the best ratio of the two. Continuing work involves completing this analysis for the period 2009-2011 (Wood et al. 2013).

c) Preliminary multivariate signals for genesis prediction

Other remote-sensing observations are being investigated for their ability to improve the genesis prediction in combination with the DAV parameter. Figure 4 shows a comparison of GLD360 lightning flash counts, DAV parameter, and cloud top temperature for Tropical Storm Estelle as well as the NHC best track wind for context. Preliminary results indicate most storms exhibit a negative correlation between minimum DAV for a given cluster and the number of lightning flashes within that cluster for developing systems prior to tropical depression designation.

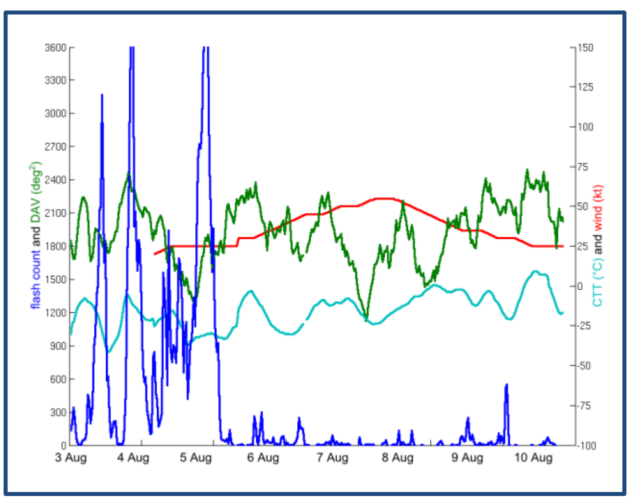

Figure 4: Time series of three of the parameters being compared (flash count (blue), DAV (green), and cloud top temperature (cyan)) for Tropical Storm Estelle as well as the NHC best track wind (red) for context.

Unfortunately, the 2010 eastern North Pacific hurricane season was one of the least active on record. Due to the small sample size used in this analysis, further testing is necessary to improve the robustness of the results. In addition, clusters developing close to land tend to have much higher counts per half hour, and a greater sample size would allow near-land clusters to be evaluated separately from over-ocean clusters. Continuing work will apply the objective tracking technique to follow all clusters and simultaneously record the corresponding flash counts over a number of seasons. The results will then be evaluated by dividing the tracked clusters into developing and non-developing groups and extracting the associated signals for each group.

d) Wind field structure from the DAV parameter

Maps of the DAV with respect to time display information on the axisymmetry of TC cloud structure. However, further analysis has revealed that the symmetric and asymmetric spatial patterns of the DAV correlate well with the corresponding spatial components of the surface wind field (e.g., Fig. 5). The spatial/temporal information in these maps along with information from Best Track and the SHIPS model are utilized to create a multiple linear regression model, which is then utilized to estimate the radii of the 34-, 50- and 64-kt wind radii for both the axisymmetric and asymmetric components of the wind field. The symmetric model has mean absolute errors (MAE) of 20.8, 12.5 and 7.3 n mi for the 34-, 50- and 64-kt wind radii. An example of a TC with variable intensity and size is displayed in Fig. 5. The asymmetric component of the wind radii are also modeled using azimuthally averaged DAV in the NE, SE, SW and NW quadrants of the TC. Using the same predictors as the symmetric model gives the best estimates of the wind radii. MAEs for the 34-kt wind radii in the NE, SE, SW and NW quadrants are 27.7, 25.2, 19.9 and 30.1 n mi respectively. The MAEs for the 50-kt wind radii for the same quadrants are 17.6, 16.7, 12.3, and 18.1 n mi. The-64 kt wind radii had MAEs in each quadrant of 10.3, 8.9, 6.9, and 9.1 n mi. This objective technique for measuring the wind radii from GOES IR imagery allows for good approximations of the wind radii on ½ hourly time basis.

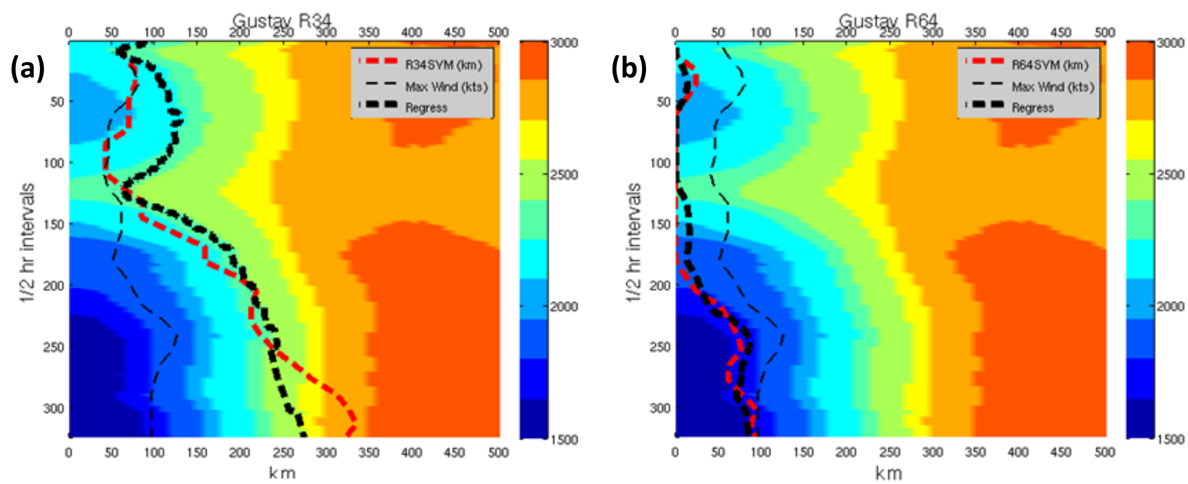

Figure 5: Hovmoller diagram of the azimuthally-averaged DAV signal plotted in color shading with values corresponding to the color bar on the right for TC Gustav. The red dashed line is the symmetric observed wind radii (km) and the thick black dashed line displays the regression line (km). The thin black dashed line displays the intensity of the TC in kts: (a) Observed wind radii and regression line for 34-kt winds; and (b) Observed wind radii and regression line for 64-kt winds. The thin black dashed line is the TC intensity in kts.

IMPACT/APPLICATIONS:

1) Intensity Estimation: To estimate and predict the TC's intensity, forecast centers make use of *in-situ* measurements that are expensive and not always available. On the other hand, satellite-based imagery provides a key, reliable source of measurements over the data-sparse tropical oceans (e.g., Ritchie et al. 2003). Several procedures have been developed to estimate the TC's intensity from satellite imagery,

among the most known ones are the Dvorak technique (Dvorak 1975), and the Advanced Dvorak Technique (ADT) developed by Olander and Velden (2007). Although the first technique is widely used, it is also subjective and produces quite different estimates depending on the operator. The second technique is well developed and while it has sensitive technical steps that can affect its performance (e.g. the TC pattern selection), it shows a lot of promise and is used by operational centers as additional information on current intensity. The technique being further developed in this research is simple, easy to implement, uses only infrared imagery, has a good performance, does not use pattern classification, and is a completely independent estimate of intensity. For this reason, this technique can enhance other TC intensity estimations generated by forecast centers around the world.

2) Genesis prediction: The ability to ascertain with some confidence that a particular cloud cluster will go on to develop into a tropical cyclone is a continuing issue for forecast centers. Again, there are techniques available to forecast centers to help with likelihood of genesis, putting concrete values or probabilities against the development of a particular cloud cluster is still more of a qualitative than a quantitative exercise. Here we are developing a fully objective, automated system that tracks cloud clusters and provides a probability of development into a tropical cyclone in a particular time frame that can be used in conjunction with other genesis techniques, or as a stand-alone tool.

3) Wind field structure: There are several potential applications for a good quality wind field. Currently we can produce a two-dimensional surface wind field of an existing TC, provide R34, R50, and R64 information by quadrant with a reasonable degree of accuracy. We can easily extend this to a three-dimensional wind field by using analytic profiles based on idealized models of TC vertical structure. However, we are exploring ways to extract vertical structure from satellite observations in order to produce a three-dimensional TC wind field that is physically based. This more realistic structure can be used to initialize forecast models.

RELATED PROJECTS:

None.

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PUBLICATIONS:

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